U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER

OFFICE NOTE 187

A Case Study of Analyses and Forecasts over Tropics with NMC Operational Models

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AUGUST 1978

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Over Tropics with NMC Operational Models

1. Introduction

In order to assess the accuracy of NMC analysis (Flattery) and prediction (7-layer) models over the data-sparse tropical regions, several 12-48 hr forecasts over Hawaiian area, for the period 19-21 April 1978, are examined. This is one of the three cases suggested by Mr. Lee (MIC Honolulu).

The height and wind fields at 1000, 850, 700, 500, and 250 mb and the relative humidity fields in the boundary layer, and the two lower tropospheric layers are obtained using a microfilm output program. These fields are examined for the Guess, Analysis, Initial, and 48-hr forecast at 12-hr intervals. The predicted precipitation at 12-hr intervals is also examined.

Small areas of (unrealistic) cross-contour flow, in some data-sparse tropical regions, are generated by Flattery analysis at all levels, even when such flows are not present in the first guess (section 2a). The equatorial boundary conditions in the initialization procedure often introduces new unrealistic marked cross isobaric flow areas.

Large areas of cross isobaric flow develop at all levels in the Tropics, in the first 12 hours of forecast (section 2b). The mass field oscillates in the region south of 20N, and the relationship between predicted wind and pressure fields is obscure. In some phase of the pressure oscillation, the winds are nearly parallel to the contours; while at another phase of the oscillation, there is marked cross-contour flow. The surface frictional effects enhance this cross-contour flow in the boundary layer.

Preliminary analysis suggests that this large oscillation in the pressure field arises due to the unrealistic imbalance between pressure and wind present in the model's initial fields in the tropics (section 4). The lateral boundary conditions in the prediction may be enhancing this oscillation which is most marked near the equator.

The analyzed relative humidity (RH) values are reduced at points south of 25N in the initialization.

$$RH_{INIT} = RH_{ANAL} * 2 \sin\phi$$

where ϕ is latitude. The initial RH, south of 20N, are less than 60% and remain so during the 48-hr predictions for the cases studied here (section 3). No precipitation is predicted by the model in these low humidity areas.

The movement of a cyclonic circulation in the region (along 30N) to the north of Hawaiian area was forecasted well by the model. The intensity and the vertical extent of the cyclone was, however, not well predicted (section 2b).

2. The pressure and wind fields

The main feature of interest is the movement of a low pressure (mid-latitude) system at 30N to the north of Hawaii. The observed central surface pressure remained almost constant (1012 mb) from 19 to 21 April. Observations and satellite loops suggest that the rainfall occurred mainly to the east and to the south of the system. The cyclonic system extended vertically to 250 mb with a northward tilt.

48-hr predictions from 00 and 12Z on the 19th and 00Z on the 20th April are examined. Predictions from 00Z on 19th are typical of the three cases and are mainly discussed below.

a. Guess, analysis and initialization

The gradient in the height of the isobaric surfaces is very weak in the tropics. Three intermediate contours are therefore drawn to depict the gradients in the tropics.

Figs. 1 to 5 show the winds and contours at 1000, 850, 700, 500, and 250 mb, respectively. HUFGES = First guess fields for analysis are normally the 6-hr F/c valid at analysis time (see Appendix) from the previous cycle of Global model. ANL = Flattery analysis and F00 = The initial field for input to the 7-layer model.

The HUFGES for the operational analysis at 00Z on the 19th are from 6-hr forecast from 12Z on 18 April. The HUFGES fields are off time by 6 hrs (see Appendix). The circulation (wind field) features at places are displaced from the corresponding features in the pressure field. For example, there is a ridge in the wind field along 22N near 140W (Fig. 2a, 850 mb). The ridge in the pressure field is at 26N. The westerly winds at 22N are in the region where contours imply winds from the east. The winds at 500 mb (Fig. 4a) are from east near 26N and between 170 to 160E, while the contours imply westerly or northwesterly winds.

The analyzed winds agree fairly well with the observations (circles) and satellite (*) derived winds. However, marked cross isobaric component is present in the low tropospheric analyzed winds in some data-sparse tropical regions. Examples of such areas are to the south and also east of Hawaii (Figs. 1b, 2b).

In the region to the south of Hawaii, a low-pressure area is analyzed at 1000, 850, and 700 mb near 10N and 160W (Figs. 1b, 2b, 3b). Available observations do not indicate such a low pressure area. The analyzed winds appear to be reasonable. The marked cross isobaric component in this area is due to the erroneous contour analysis.

The surface bogus data which was introduced for the operational analysis is shown (Fig. 6) together with some station data reports. The ship and surface reported pressure agreed well with the bogus pressure data. There were no reported pressures near 10N 160W. The reported data and bogus surface pressure data imply that the 120 m contour in the analysis, between 160W to 170W, should be in somewhat northward location than its position in HUFGES. The analysis therefore has a deeper trough and gives rise to somewhat lower pressures in southern latitudes. The contour 90 in the equatorial region is nearly the same in ANL and HUFGES, so that lowering of height values near 10N 160W gave rise to a low pressure area. An examination of the gridprint of heights at 1000 mb in this region showed that the heights are about 20 m lower in ANL than in HUFGES near 10N 160W. Winds in this region in the HUFGES and ANL are mainly from the east. They blow across the low pressure in the ANL but have much smaller cross isobaric component in HUFGES.

At 1000 and 850 mb, in the ANL, there are westerly winds to the north and east of the Hawaiian islands, where contours suggest winds from the east. The ship reported surface winds and the surface winds reported over the Hawaiian Islands are shown in Fig. 8. These winds suggest an anticyclonic circulation over the Hawaiian Islands.[1] The anticyclone is reflected in the analysis (fig. 1b) with westerlies to the north and east of the Hawaiian Islands. (The ADPSFC dump on monthly Archive Tape is at 0930Z. It is assumed here that even though some ship reports may not be available at the operational analysis time, the Hawaiian Island surface data was available at the operational analysis time ≈ 0330Z.)

The surface bogus data and the ship and land surface reported pressure (Fig. 6) do not suggest a trough near 20N 141W as shown in the analysis. A comparison of HUFGES and analysis shows that between 150W and 130W the analysis did not change the HUFGES contour field at 1000 mb inspite of a different contour pattern suggested by the bogus and ship reports. (The ADP SFCSHP DUMP is at 0929Z and SFCBOG at 0325 Z.) Even if some ship reports were not available at the operational analysis time, the bogus pressures do suggest contour pattern different than that given by analysis.) It is not clear why the Flattery analysis did not analyze the contour field to fit the bogus and other data in this region.

The analyzed wind field is apparently similar to the geostrophic wind field implied by contours to the north of 40N. In the tropics, this geostrophic constraint is relaxed in the analysis. The wind analysis in the tropics is nearly independent of the pressure field and gives rise to unrealistic cross isobaric flow patterns. At places, the analyzed wind is

[1]If the stations reporting northerly winds (Fig. 7) are located at the northern tip of the islands, then these northerly winds may be due to sea breeze (00 GMT = 2 PM local time).

opposite to direction to that implied by a wind in balance with the pressure field.

The initialization procedure for the 7-layer model introduces larger areas of cross isobaric flow in the tropics (e.g., compare Fig. 4c with 4b). Note that the cross equatorial flow pattern in the analysis at 250 mb is quite different than that in the initialized flow (Fig. 5). The reasons for these undesirable changes from analysis to initialization are discussed in section 4.

b. <u>Predicted contour and wind fields</u>

Figs. 8 to 12 show the predicted winds and contours at 1000, 850, 700, 500, and 250 mb.

The change in wind direction, during the period t = 12 to t = 48 hrs, is generally less than 45^0 at all levels in most of the tropical area south of 20N. There is, however, large oscillation in the pressure field. For instance, between 150W to 180W, the pressure gradient at 850 mb (Fig. 9b) is in the east-west direction (contours are N-S oriented) while at 36 hr (Fig. 9c) the pressure gradient is in the north-south direction (contours are E-W oriented). These changes in the orientation of contours occur at all levels. There is no clear oscillation in the wind field; there is, however, a marked oscillation in the pressure field.

By the first 12 hours a large cross-isobaric wind component develops in the tropics at 1000 mb. The winds become north-north-easterly to the east of Hawaii and remain so during the rest of the period (48 hr). Since the Hough analysis does not have any frictional terms, the development of marked cross isobaric flow in the tropics (f small) during prediction may be caused mainly by the frictional retardation of surface winds. The

7-layer model was integrated to 48 hrs with no surface friction. The cross isobaric component at 1000 mb in this prediction was weaker. The oscillation in the pressure field was, however, present in this case also (Fig. 15).

The movement of the cyclone to the north of Hawaii is predicted well by the model. The height at 1000 mb rises from 105 to 135 m in the first 12 hrs. The system weakensmore during the next 24 hrs. The central surface pressure in the actual cyclone remained at 1012 mb during this period. The intensity of the system is therefore not well predicted by the model. Note that initially a closed circulation exists to 250 mb to the north of the low level cyclone. In the real atmosphere, the satellite winds suggest that cyclone deepened at 250 mb (2000Z). In the prediction the cyclone weakens into a trough by 1912Z and remains weak thereafter.

3. Precipitation

Satellite loops suggest that most rainfall must have occurred to the east of the cyclone and in a narrow band extending southeastward from it up to 20N. 24-hr rainfall amounts of 1-2" on 20 and 21 April are reported by several Hawaiian Island stations, situated to the north of 20N.

The model predicted precipitation for 12 hrs ending 1912Z and 2000Z are shown in Figs. 13a and 13b, respectively. Clearly, the rainfall to the east of the system along 30N is well predicted by the model. No rainfall is predicted over the Hawaiian Islands. Note that the vertical motion is, however, weak upward at 700 mb (Fig. 13c) over the Hawaiian area.

Fig. 14 shows relative humidity field in first tropospheric layer in ANL, INITIAL and 24-hr forecasts. The analyzed relative humidity of 60-80% in the tropics, south of 25N is reduced to 50% or less in the initialization procedure. The relative humidity remains less than 60%

throughout the 48-hr prediction period in this area and no rainfall is predicted by the model inspite of (weak) upward vertical motion.

4. Initialization of the 7-layer model in the Tropics

Numerical results from a 48-hr prediction with the 7-layer model (section 2b) show that the pressure field in the tropics oscillates during the prediction. Two possible causes of this oscillation are: (1) There exists a large imbalance between initial pressure and wind fields; (2) the lateral boundary conditions. The points on the lateral boundary lie in the Southern Hemisphere close to the equator.

We now present the initialization procedure for the 7-layer model and show that the present procedure does give rise to large imbalance between the initial pressure and wind fields.

The initial fields for the 7-layer are derived from the Hough analysis. These fields are changed in the initialization procedure to the south of 9N. The procedure is as follows:

The data used is on mandatory constant pressure surfaces (65 * 65). Grid points lying between the rings are considered. A ring is a latitude circle. The area of forecast is a rectangle. The outermost ring considered lies completely within this rectangle and is 31.5 grid points from the pole. This ring is just outside the equatorial circle and is referred to as ring 1 in the main 7-layer initialization program. Ring 2 is 30.5 grid points from pole and so on.

The u and v components of the wind, temperature, tropopause temperature and pressure are expanded as follows: Consider u component of the wind <u>at a single level</u>. The average value of u over all grid points which lie between ring 2 (30.5 grid points from pole) and ring 3 (29.5 grid points from pole) is calculated. This average value[2] is put at all points which lie (in the rectangle) equatorward of ring 3. Then, new values of u at points between lateral boundary and ring 3 are obtained by relaxing

0 = .5*(u(I+1,J+1) + u(I+1,J-1) + u(I-1,J+1) + u(I-1,J-1)) - 2*u(I,J),

to the accuracy of 1 (for velocity field it is 1 m s^{-1}, for temperature $1^{o}C$). These new values of u, between the lateral boundary and ring 3, are then smoothed (twice) heavily (nine point smoother with smoothing element = .5). This above entire procedure is repeated at all levels for variables noted above and is carried out in the subroutine EXPAND and the procedure is referred to as expansion.

Next, each of the above fields in rings 1 to 6 are heavily smoothed in subroutine SHUV and lateral boundary conditions are imposed. The nine-point smoother is used with the smoothing element = .5. In SHUV, ring 1 is smoothed first alone, then ring 1 and ring 2 are smoothed using smoothed ring 1 values from previous smoothing step, and so on. In final smoothing pass, all the points in rings 1 to 6 are smoothed. Ring 6 is roughly at 9N.

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[2]Consider a hypothetical case where there are n data points on a latitude circle distributed symmetrically with respect to the pole and wind everywhere is easterly 10 m s^{-1}. If we consider the polar spherical (earth) coordinate system, the average of wind at the n data points (on a latitude circle) is easterly 10 m s^{-1}. However, if we average separately the u and v components of the wind on polar stereographic projection (as is our case: u and v are on 65 * 65 grid) for these n points on a latitude, the average wind would come out to be zero ($\overline{u}$=0,$\overline{v}$=0). It is not clear what is modeled with such averaging process in the initialization program?

The smoothed (and with boundary conditions imposed) u and v components of winds are used to calculate vorticity in the center of the grid box. These grid box values are averaged to give grid point values of vorticity. A geostrophic balance equation (Eq. 1) is solved (for points between lateral boundary and ring 6) to derive height field; 'f' is assumed constant = f_{9N}.

$$g\Delta^2 Z = f\zeta \quad (1)$$

In the relaxation procedure the wall condition on Z, viz. Z at first interior grid point equal to Z at the adjacent grid point on boundary is imposed. The height field so derived is once smoothed and desmoothed (introducing imbalance ?) at the points between the lateral boundary and ring 6. The relaxation is done in the subroutine INBAX.

At present, the above relaxation is carried to the accuracy of 10 m. In the relaxed area, f = f at 9N $\approx 2.5 * 10^{-5}$ sec^{-1}. For $\Delta x \approx 250$ km in the tropics for the 65 * 65 grid used for initialization, an error of 10 m between two grid points implies very large error in the geostrophic wind. The relaxed height field so derived therefore has large areas of imbalance. For this purpose note the larger cross isobaric component in low latitudes in F00 data compared to ANL at 850, 500, and 250 mb.

We mention that the temperature field in the expanded region is not forced to be in hydrostatic balance (with the newly derived Z field). In transformation from p to σ (in PE initialization) the effect of the temperature field is, however, small.

5. Suggestions for further experimentation for improving numerical forecasts in the tropics

A marked pressure oscillation in the tropics is present in the 7-layer prediction and it gives rise to unrealistic cross contour flow patterns. Use of realistically large relative humidity in the presence of such flows may induce excessive precipitation and give rise to computational instability. The initial relative humidity is therefore reduced in the tropics for the model run (section 1). The oscillation in the pressure field needs to be therefore reduced so that realistically large values of relative humidity can be used in the tropics for better prediction. For this purpose we suggest the following:

(1) The relaxation to obtain geostrophic height field from the wind in the tropics (subroutine INBAX) should be performed to the accuracy of 0.1 m (and not 10 m as is presently done). If the run with corrected geostrophic balance (see Footnote 3, page 12) does not considerably reduce the pressure oscillation, then the tests should be carried out to see if a nonlinear balance equation to obtain initial Z field in the tropics would reduce the pressure oscillation.

(2) The lateral boundary condition in the 7-layer model implies complete imbalance. Consider the boundary conditions:

$$U_B = U_{B-1}$$
$$V_B = -V_{B-1}$$
$$Z_B = Z_{B-1}$$

where B is a point on the boundary parallel to X axis and B-1 is the first interior point next to B. Now if V_{B-1} satisfies geostrophic law ($V_{B-1} = \frac{g}{f}(\frac{\partial Z}{\partial X})_{B-1}$), then V_B must be equal and opposite to the geostrophic 'V' implied by distribution of Z on the boundary. Similarly $Z_B = Z_{B-1}$ implies that geostrophic U between B and B-1 is zero; this is not implied by imposed boundary condition $U_B = U_{B-1}$. Note that these boundary conditions are imposed in obtaining geostrophic Z field in INBAX from Eq. (1)[3]. The NGM model uses somewhat different lateral boundary conditions and initialization in tropics than 7-layer model. The case of 1900Z April 78 is being run with NGM model to see if any oscillations are present in the NGM predictions. The 7-layer model's boundary conditions should be re-examined if NGM run gives better results inthe tropics.

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[3]Eq. (1) was relaxed to the accuracy of 0.1 m in the initialization procedure. Although the cross contour flow was considerably reduced in some areas (south of 9N), it remained nearly unchanged in other areas (south of 9N, see Fig. 16). This suggests the following

ϕ obtained from Eq. (1) is related to u and v by relations:

$$u = -\frac{1}{f}\frac{\partial \phi}{\partial y} + C_1(x,y) \qquad (2a)$$

$$v = \frac{1}{f}\frac{\partial \phi}{\partial y} + C_2(x,y) \qquad (2b)$$

$$\frac{\partial C_1}{\partial y} = \frac{\partial C_2}{\partial x} \qquad (2c)$$

C_1 and C_2 are not zero because u and v do not satisfy the geostrophic law on the boundary. This is noted above to be the case on the lateral boundary. The ANL fields (figs. 1 to 5) show that at 9N (the interior boundary in the relaxation), u and v also are not in geostrophic balance. A solution to this problem is to adjust the wind on points (B-1) so that $\oint v_N d\ell$ on (B-1) is zero and relax (1) between (B-1) points and the internal boundary which can be taken at a more northerly location where geostrophic law holds reasonably well in the ANL fields.

(3) In data sparse tropical regions, there are areas where the analyzed winds are opposite in direction to those implied by the winds in balance with the pressure field (the geostrophic constraint is relaxed in the tropics in the Hough analysis). The analyzed wind field appears to be more reasonable than the pressure field. It would therefore appear desirable to use a nonlinear balance equation to obtain Z field from wind field (replace INBAX) in the entire tropics in the initialization.

(4) The equator is very close to the lateral boundary in the 7-layer model. The cross equatorial flow is therefore unlikely to be represented well in the present model (see Fig. 5c). Fluxes associated with these flows, if represented realistically, may influence meteorological conditions at 20N in about 24 hrs. in the prediction. In order to predict over the Hawaiian region for a period beyond 24 hours, it would be necessary to integrate a model with lateral boundary, far in the Southern Hemisphere.

APPENDIX

Guess fields for operational Flattery analysis

Under somewhat abnormal operational conditions, the present operational codes are apparently set up so that operational Flattery analysis does not use the guess fields derived from the latest Global forecast. It may use Global forecast valid 24 hrs or more prior to the analysis time, even though a Global forecast valid for 18 hrs prior to the analysis time from a more recent cycle and an operational analysis from the previous (12 hr off time only) operational forecast hour is available. We illustrate this for the case of 19 April 1978.

1. Cycle 1800Z

   ↓ Global Forecast to

   1806Z (write on disks T06Z,T12Z)

   (Reinitialize)

   ↓ Global Forecast to

   1812Z (write on disks T12Z,T00Z)

2. Cycle 1812Z

   ↓ Global Forecast to

   1818Z (write on disks T18Z,T00Z)

   (Reinitialize)

   ↓ Global Forecast to

   1900Z (write on disks T00Z,T12Z)

   not completed on 18th.

3. Final cycle 1900Z did not run.

The HUFGES for 00Z operational analysis is read from T00Z file, therefore for 1900Z operation run, the guess was 6-hr forecast from 1812Z (from cycle 2 above).

The HUFGES for 12Z operational analysis is read from T12Z file, therefore for 1912Z operation run, the guess was 12 hr forecast from 1800Z (24 hr off time). The 6-hr forecast from 1812Z (cycle 2 above) or the operational 1900Z analysis would have given better guess fields.

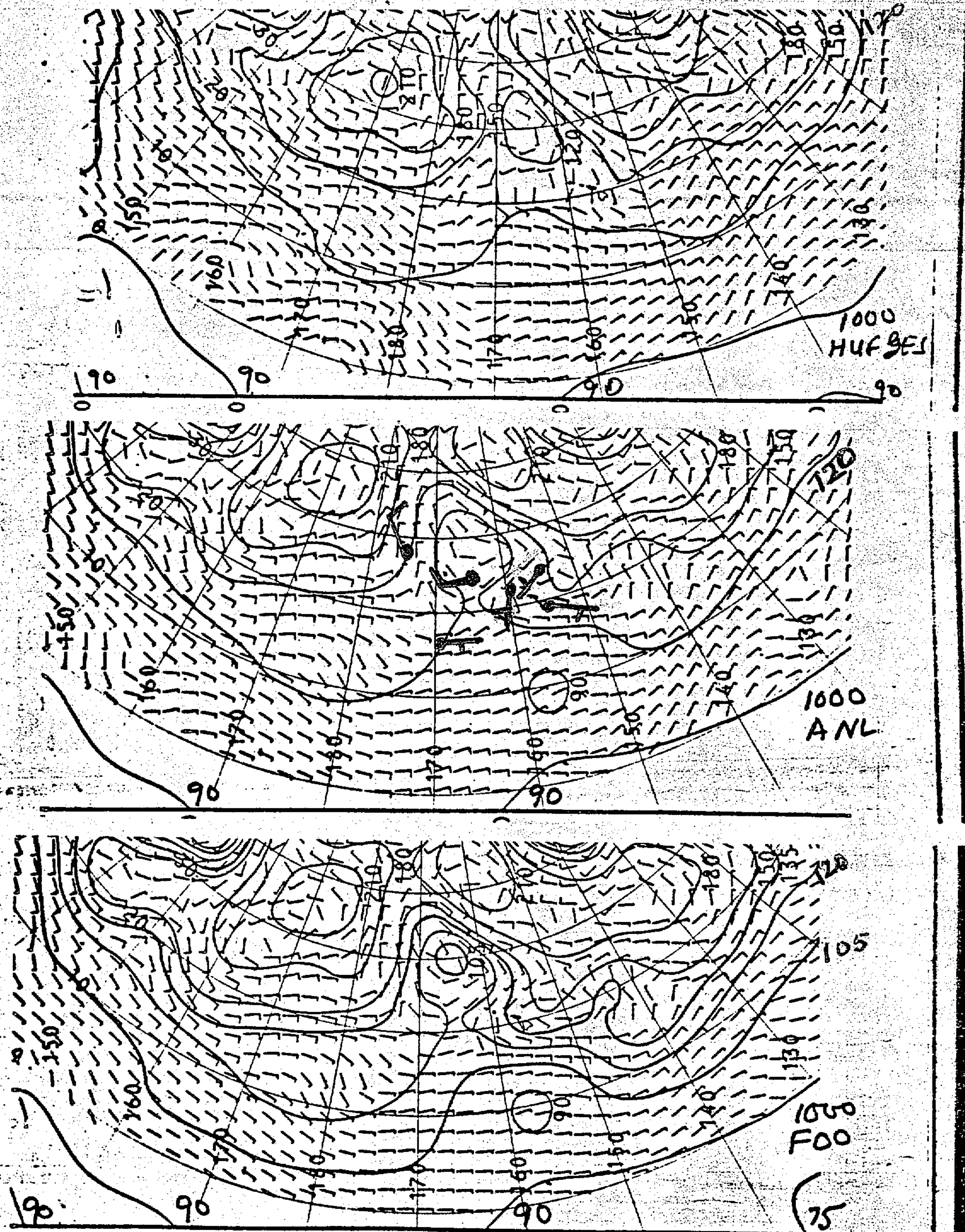


Fig. 1 Winds and Height analysis at 1000 mb (a) HUFGES, (b) ANL, (c) FOO. ⌐ = 5 m s^{-1} ⌐ = 10 m s^{-1} in all figs. Some 1000 mb wind and ship reported winds are also shown (•).

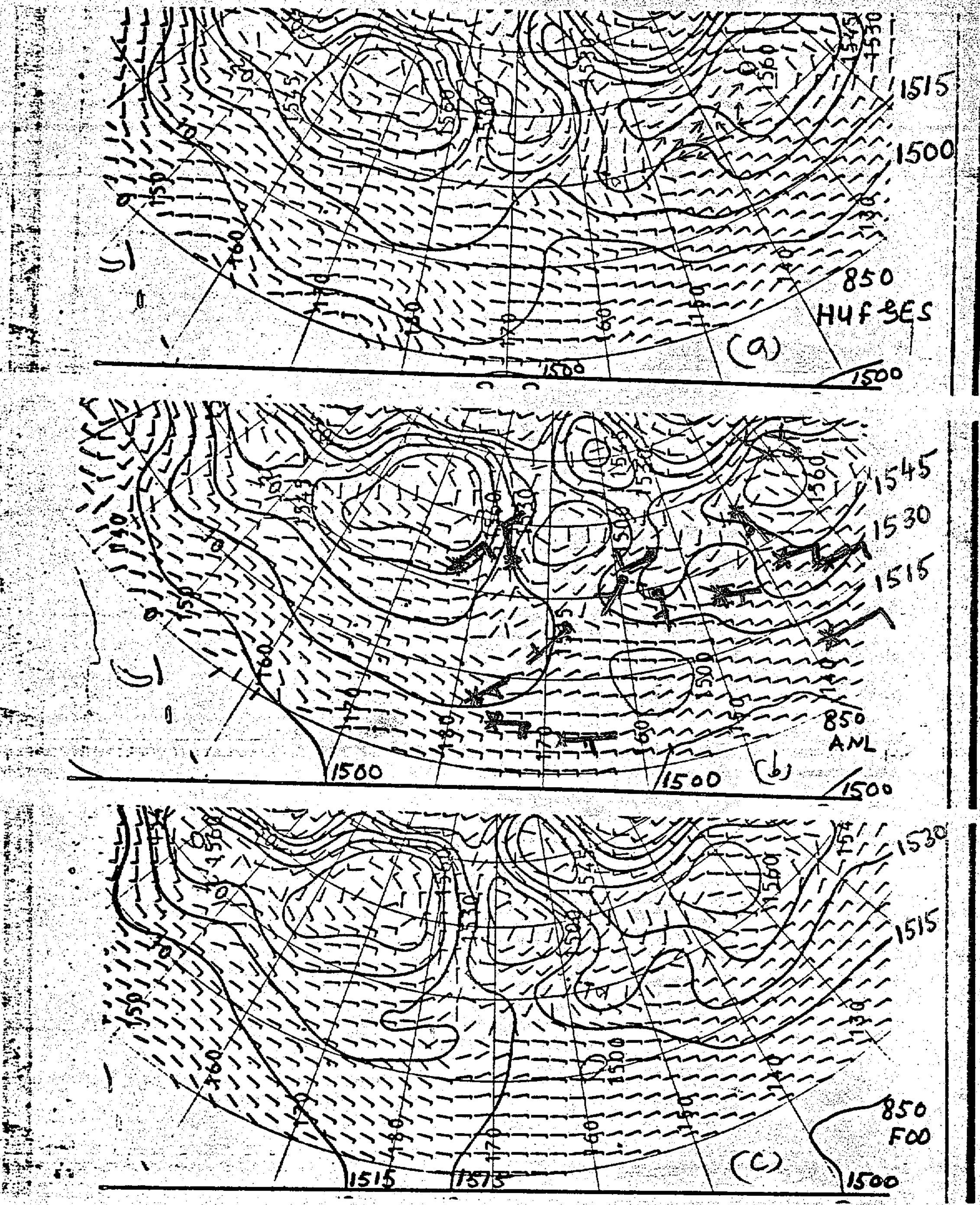


Fig. 2. Winds and height analysis at 850 mb (a) HUFSES, (b) ANL, (c) F00. Wind barbs are in m s-1 in all figs.

* Low level sattelite winds.

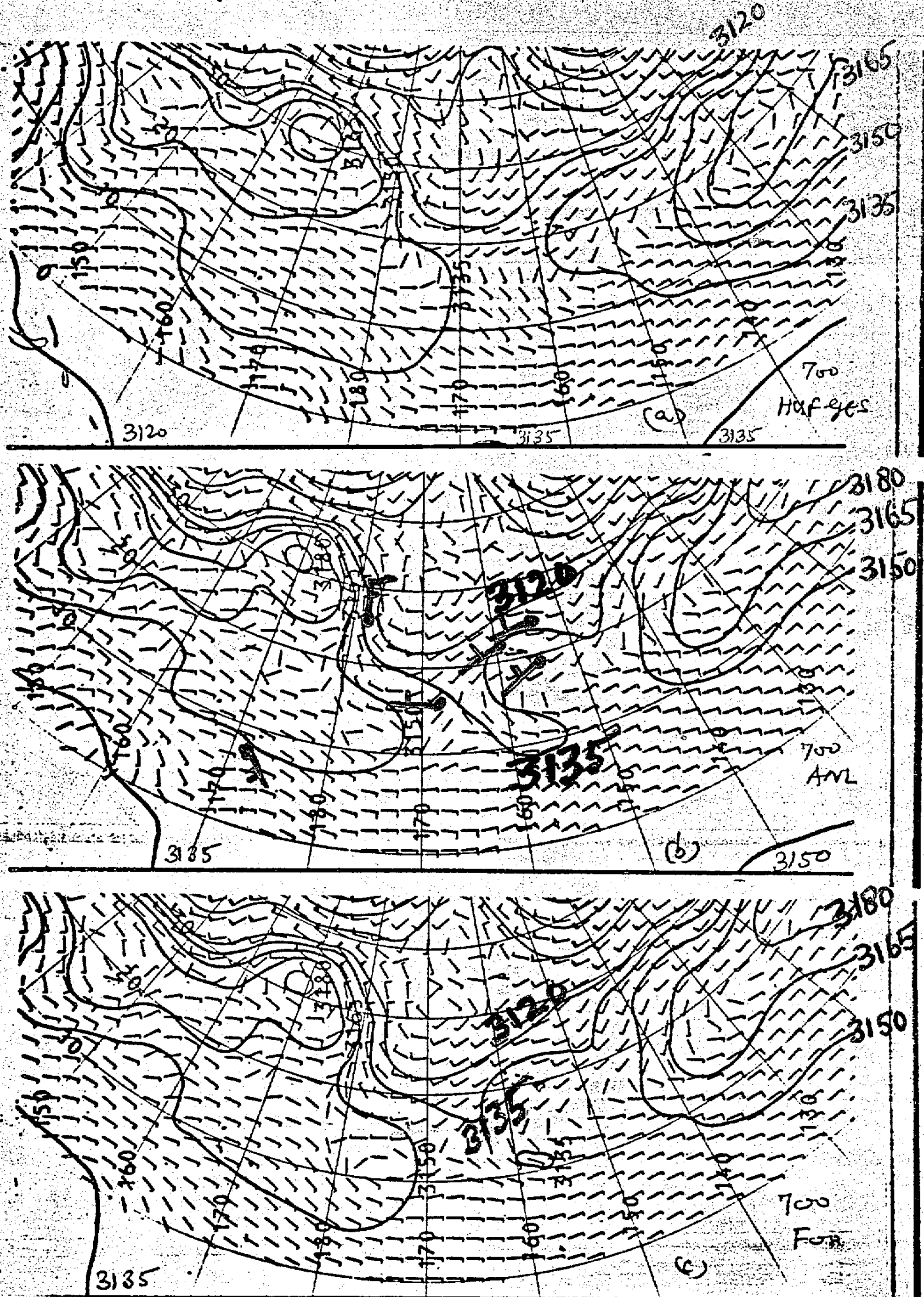
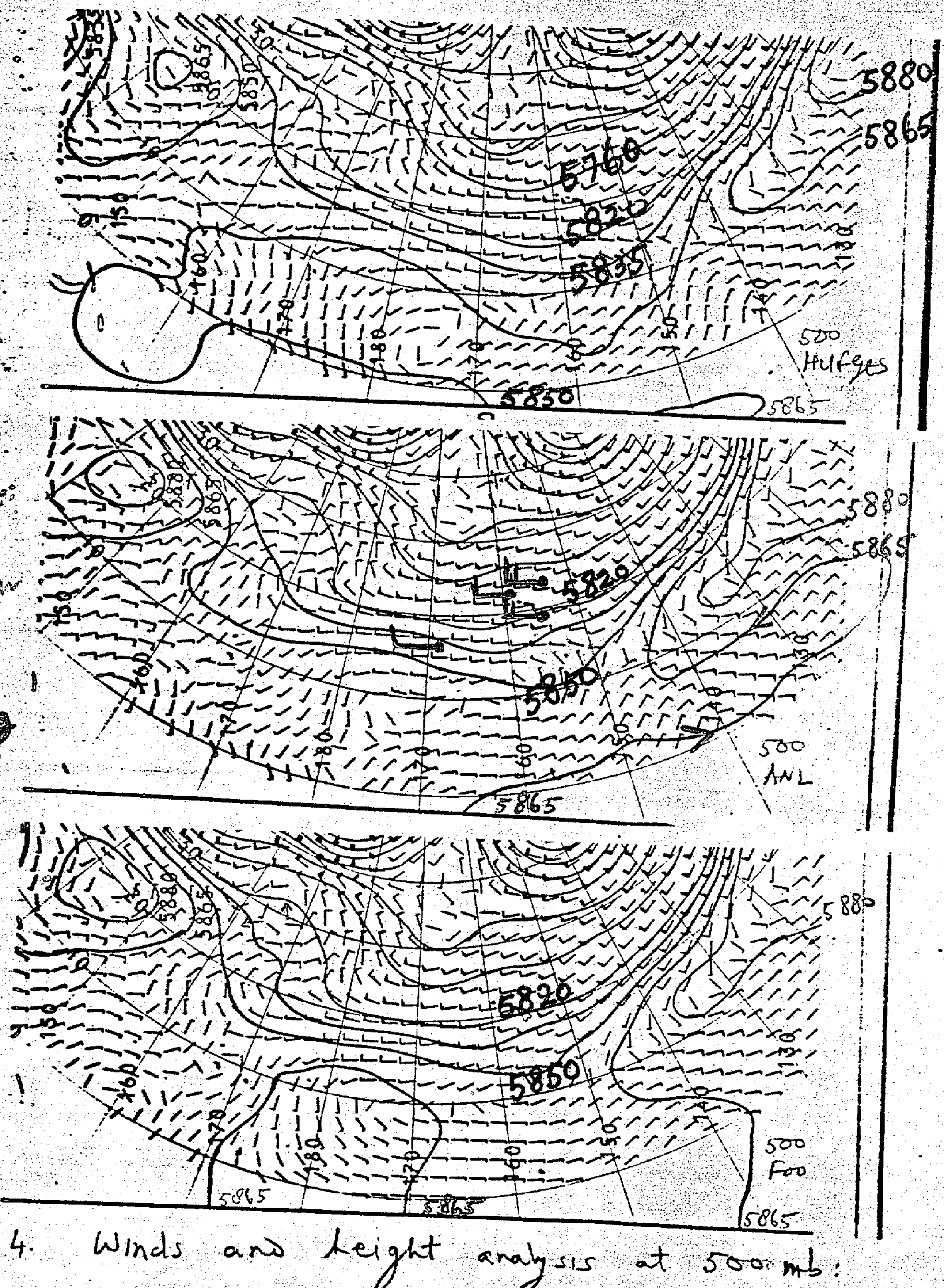
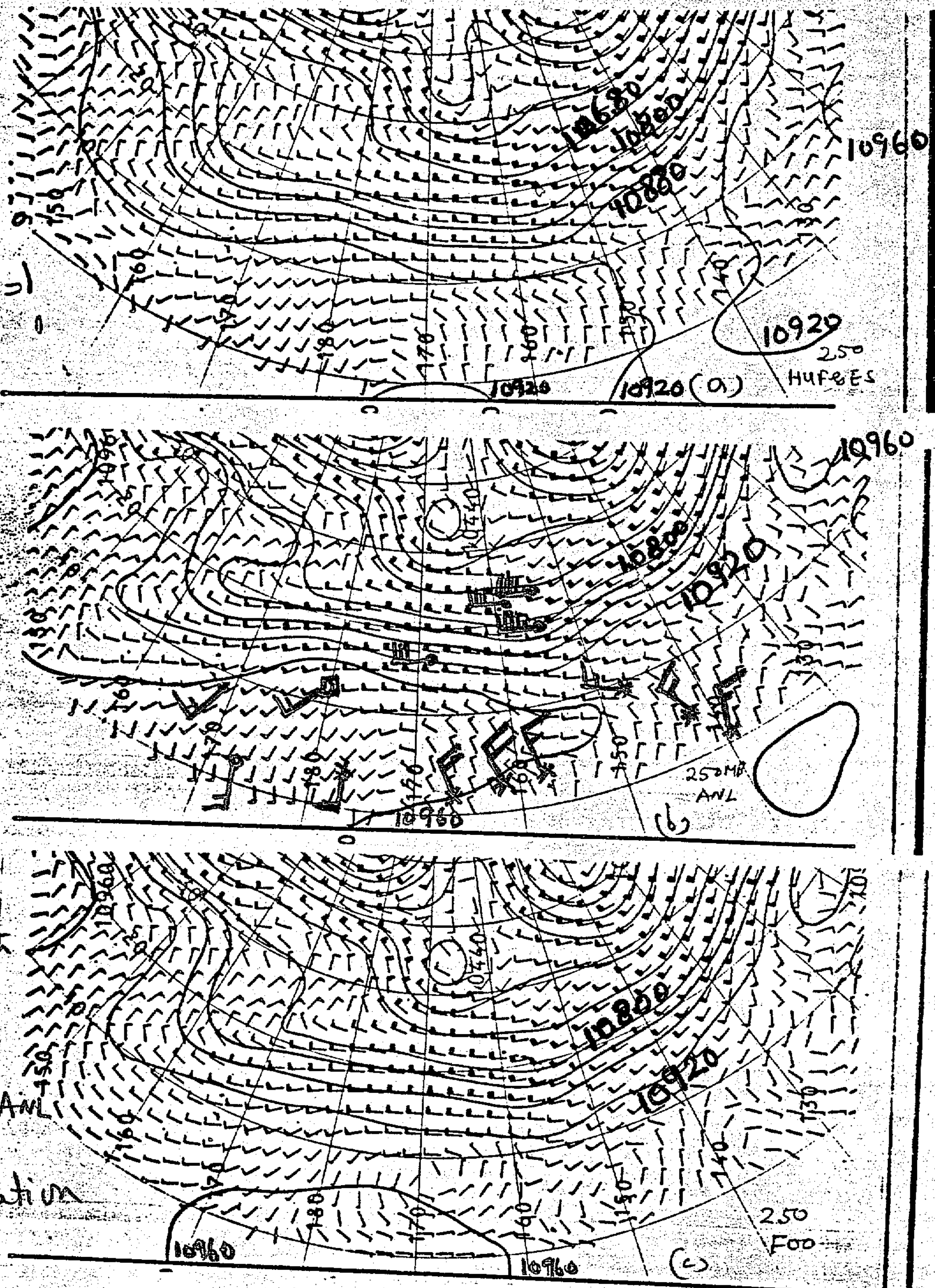


Fig. 3: Winds and Height analysis at 700 mb.
(a) H4FGES, (b) ANL, (c) FOO



In ANL, Note that: Between 160W and 130W, contour 5865 runs from W to E close to the equator, ~~implying~~ sterly ~~winds~~. ctual winds are easterly.

Fig. 4. Winds and height analysis at 500 mb: (a) HUFGES, (b) ANL, (c) FOO



Large area with northerly winds near the equator (140W to 170W) in ANL is changed in the initialization

Fig. 5. Winds and height analysis at 250 MB: (a) HUFEES, (b) ANL, (c) FOO.

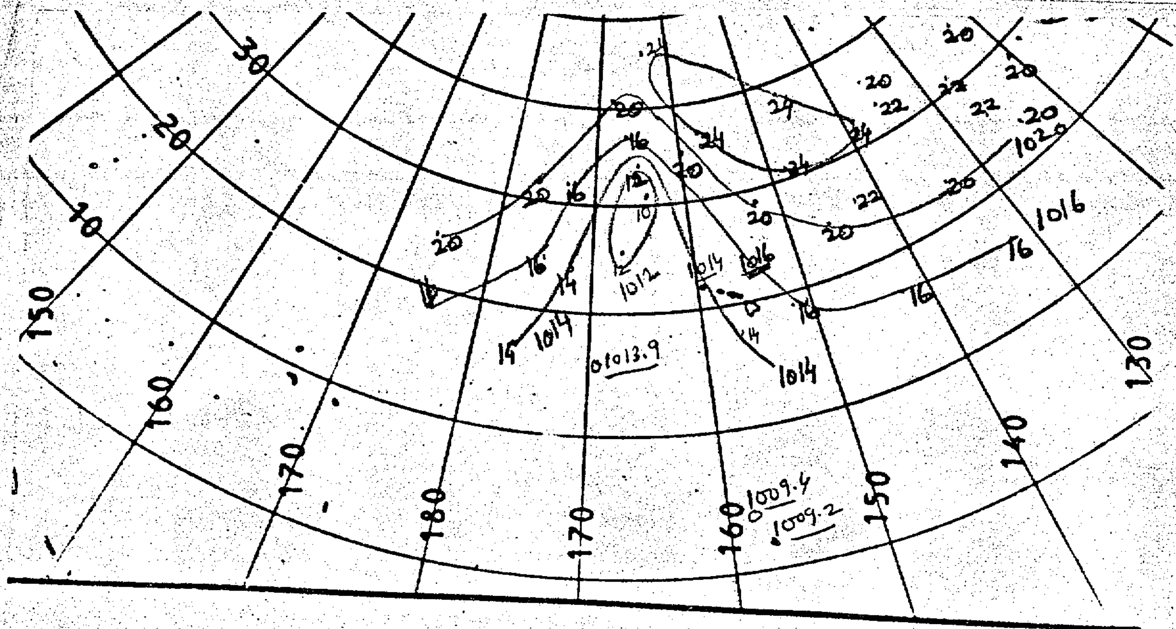


Fig. 6. SFC bogus data with some land and ship observations (underlined). Units = pressure in mb (16 = 1016 mb) 19 April '78 00z.

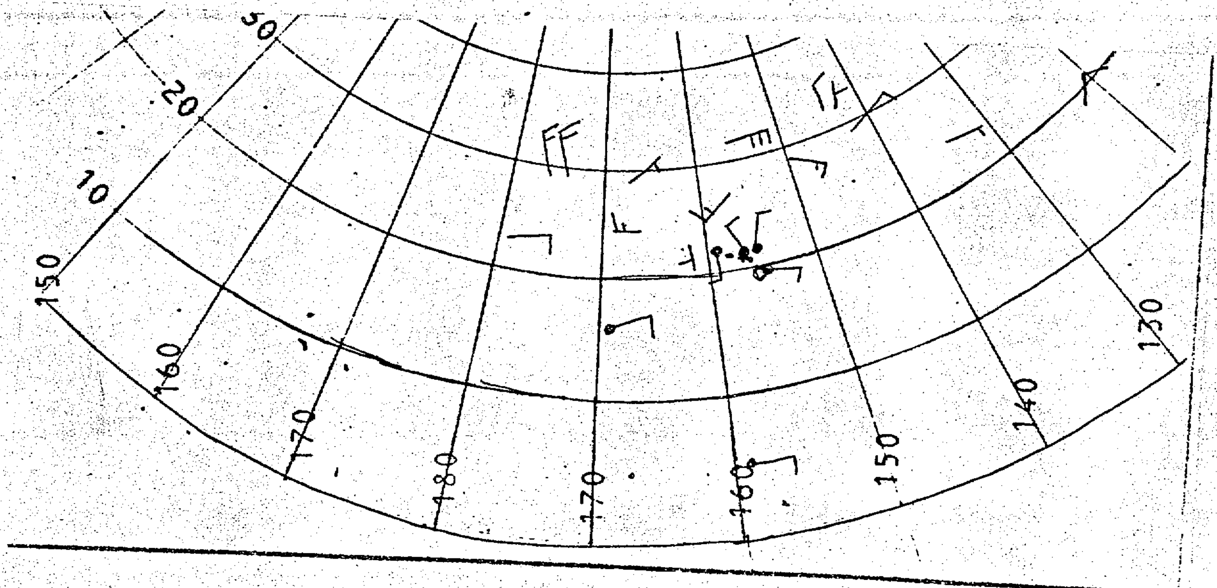


Fig. 7. station surface winds (o—) and ship reported winds at 00z 19 April 1978.

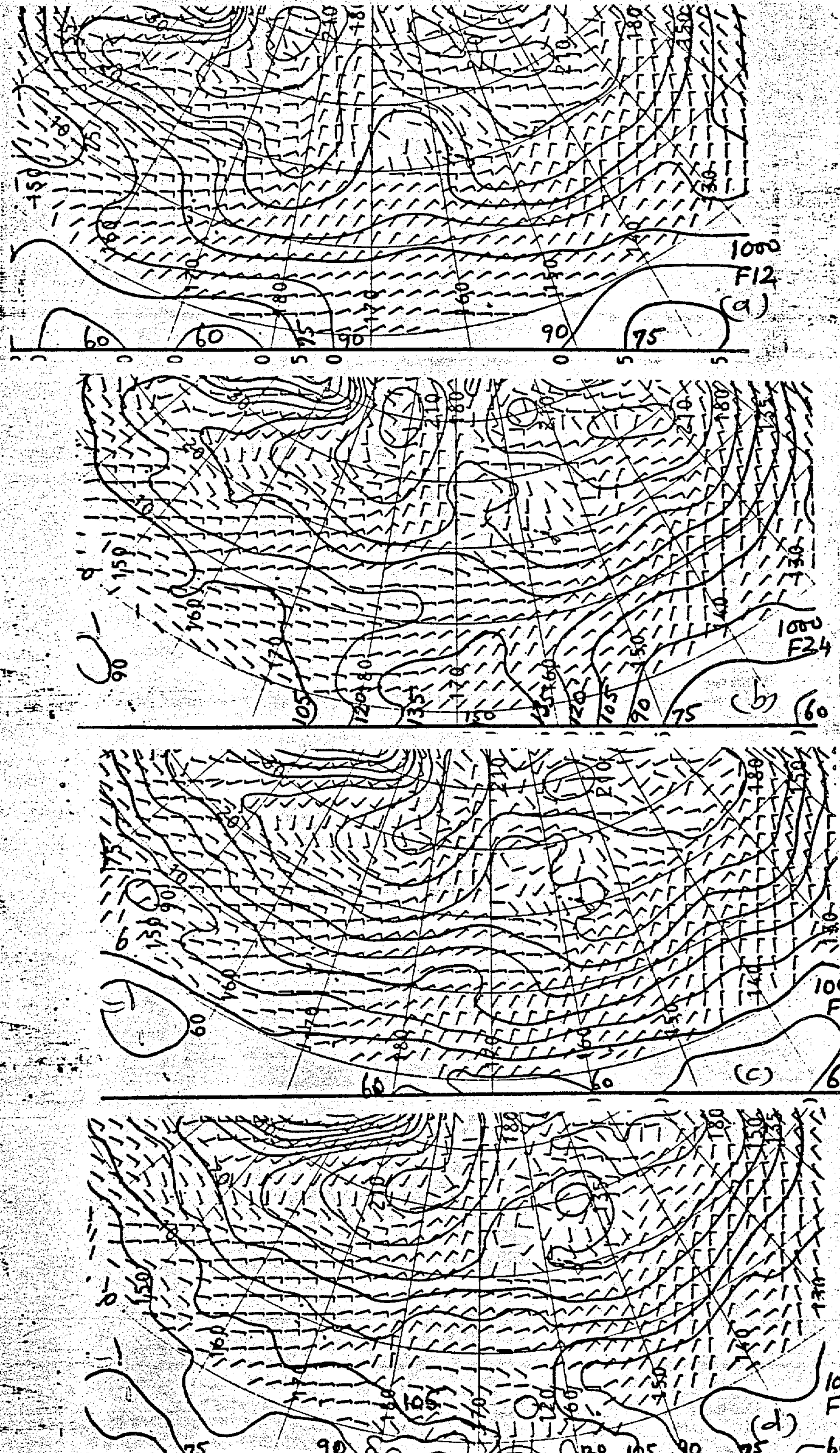
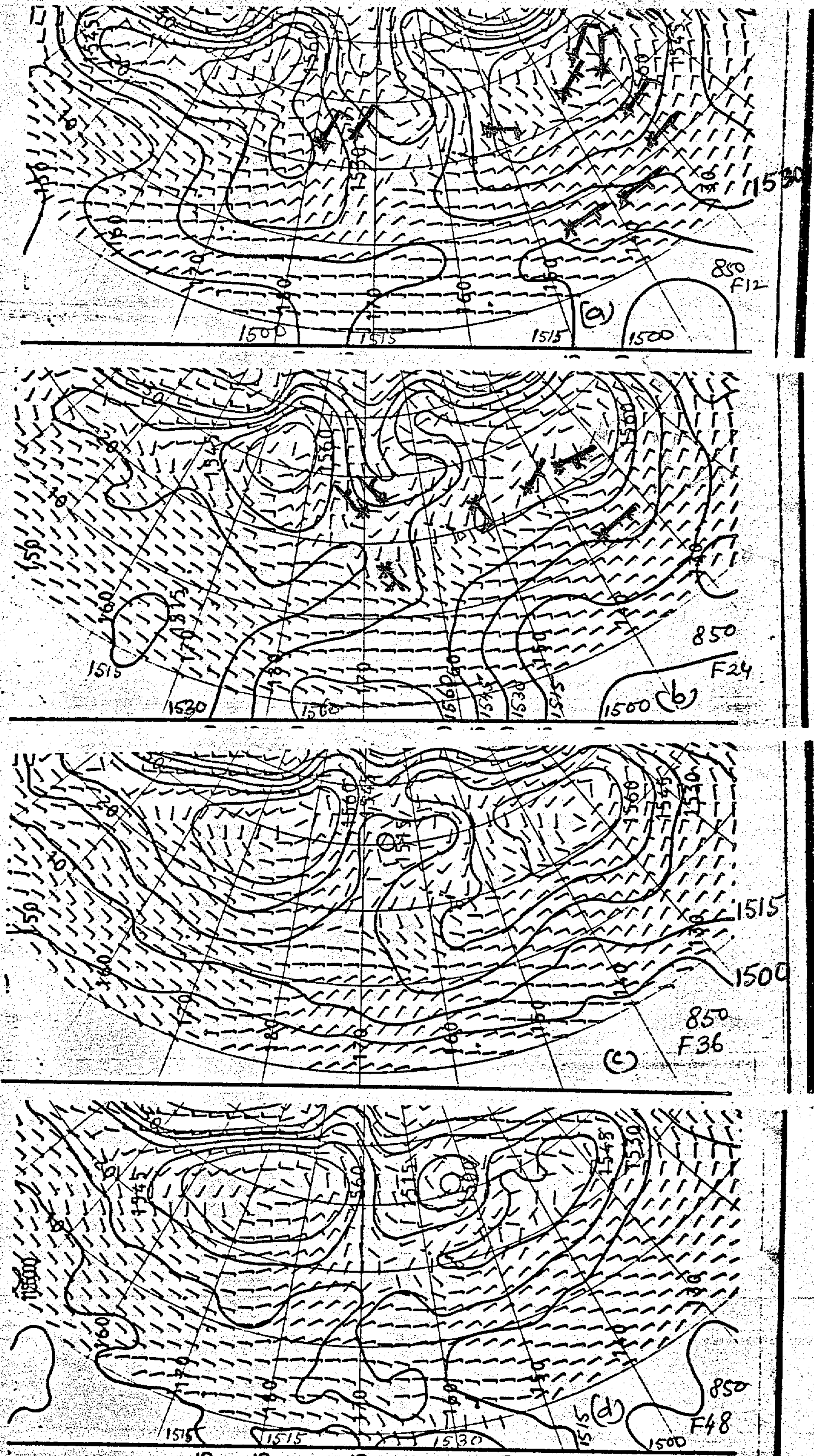


Fig. 8. Predicted winds and height analysis at 1000 mb.
(a) t = 12, (b) t = 24, (c) t = 36, (d) t = 48 hr.



* Low level satellite winds

Fig. 9. Predicted winds and height analysis at 850 mb.
(a) t = 12, (b) t = 24, (c) t = 36, (d) t = 48 hr.

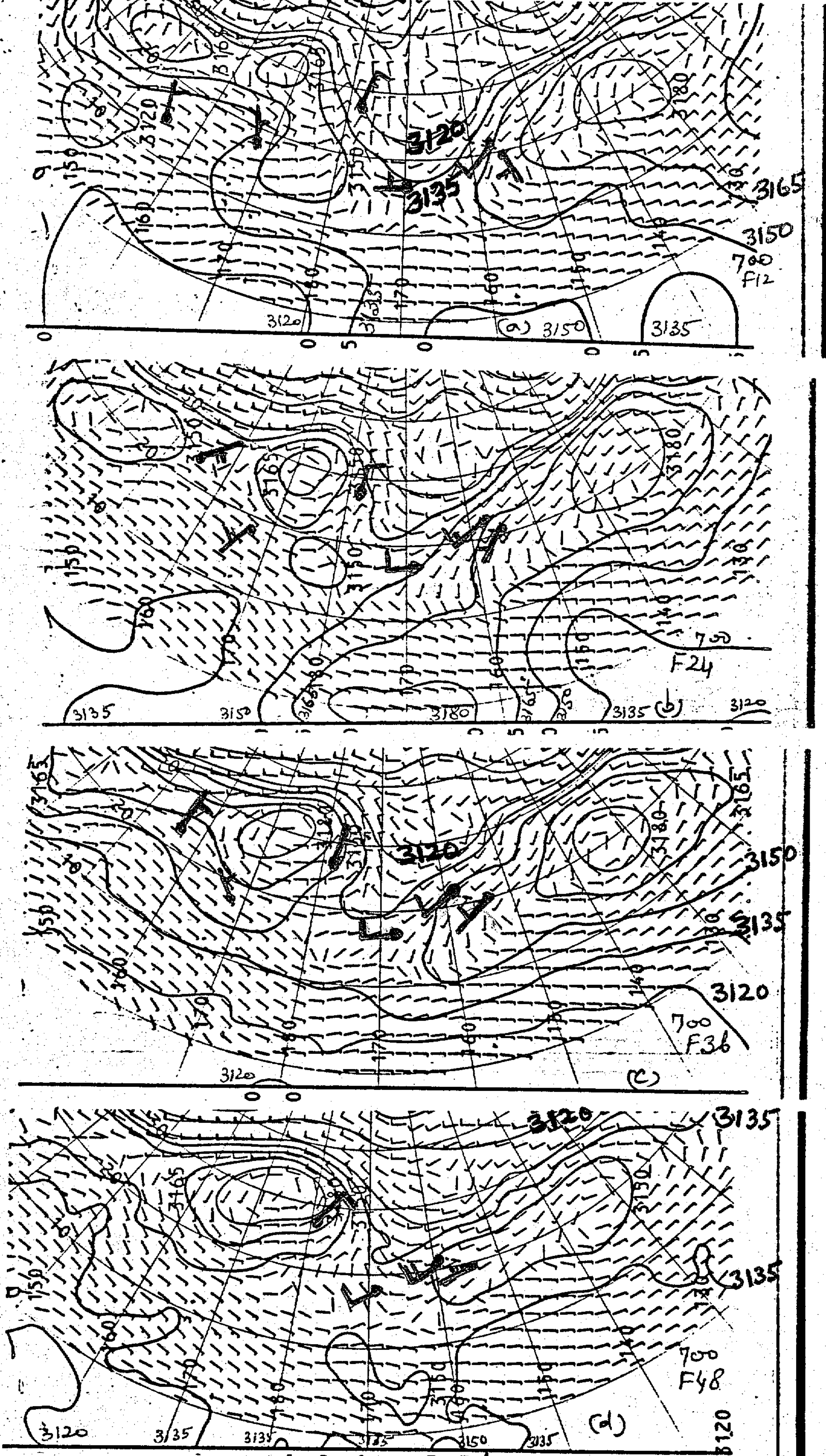


Fig 10. Predicted winds and height analysis at 700 mb.
(a) t=12, (b) t=24, (c) t=36, (d) t=48. •= station winds

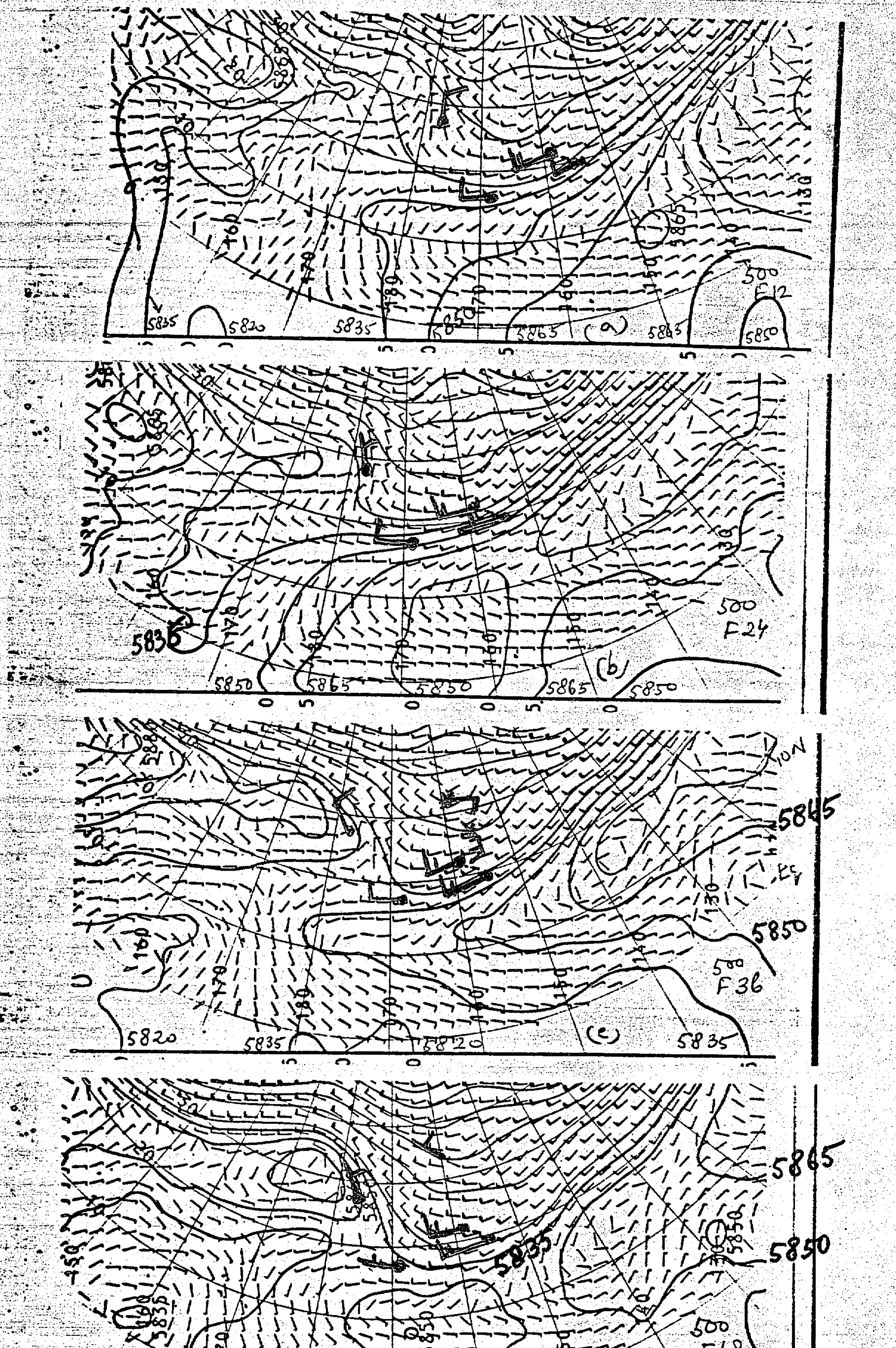


Fig. 11. Predicted winds and height analysis at 500mb. (a) t=12, (b) t=24, (c) t=36, (d) t=48. •= station winds

* Note that satellite and A/c reports suggest northerlies near equator (140W to 170W) at all hours: not simulated by the model.

*= satellite winds

□= A/c reports

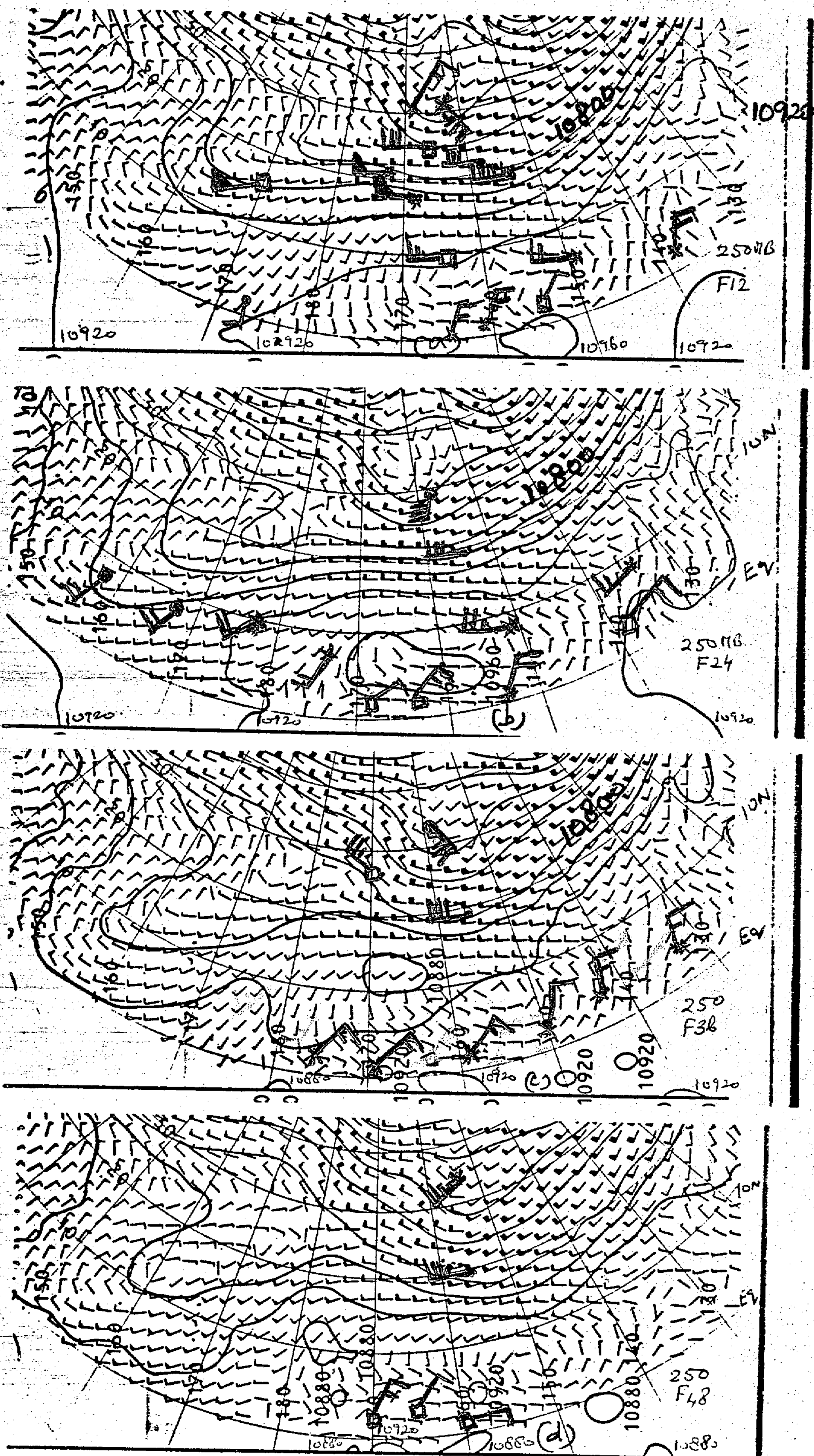


Fig. 12. Predicted winds and height analysis at 250 mb: (a) t = 12 hr, (b) t = 24 hr, (c) t = 36 hr, (d) t = 48 hr

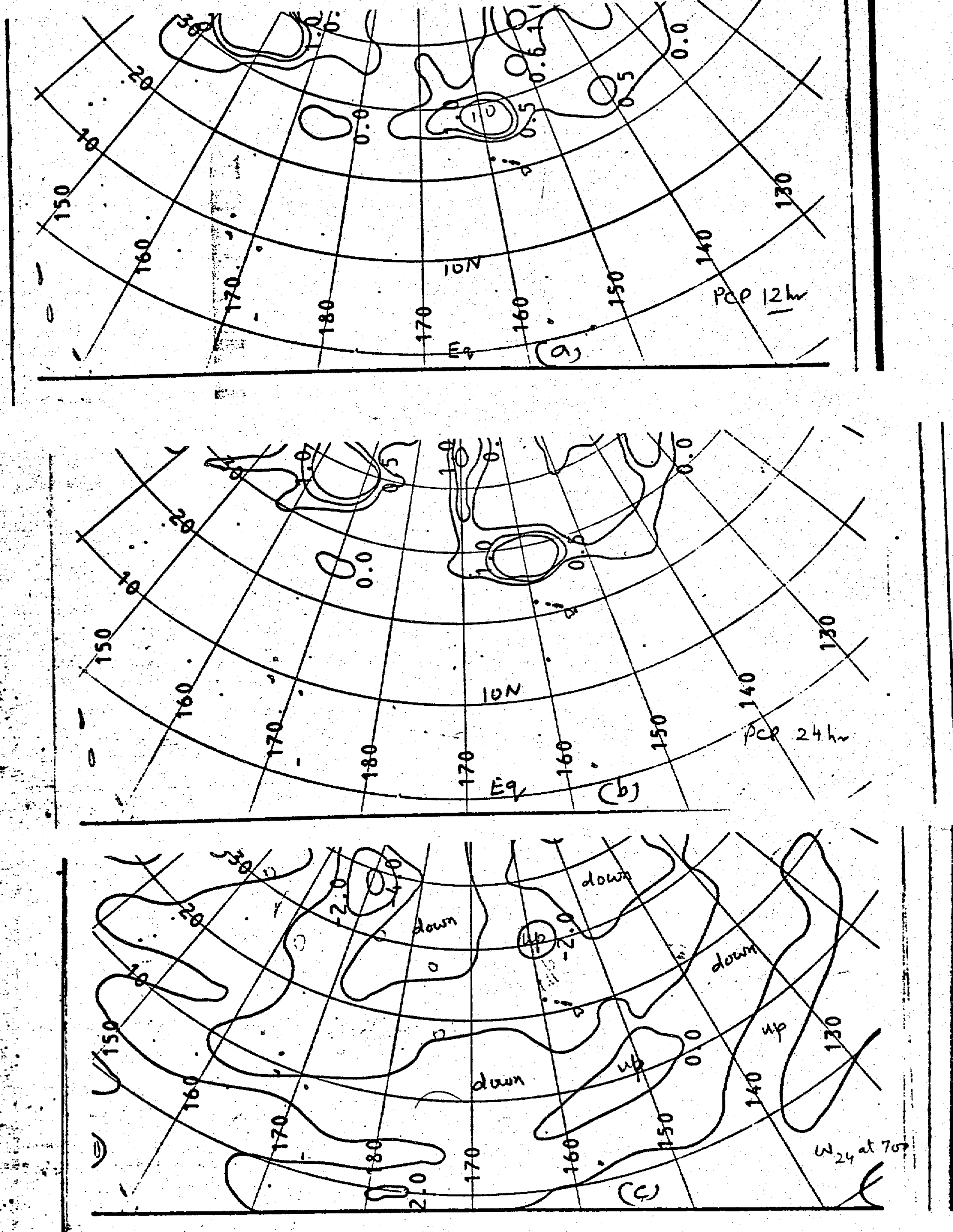


Fig. 13. 12 hr predicted rainfall (cm): (a) t = 0–12 hr, (b) t = 12–24 hr.
(c) vertical p-velocity (10^{-3} mb s^{-1}) at 700 mb. t = 24 hr.

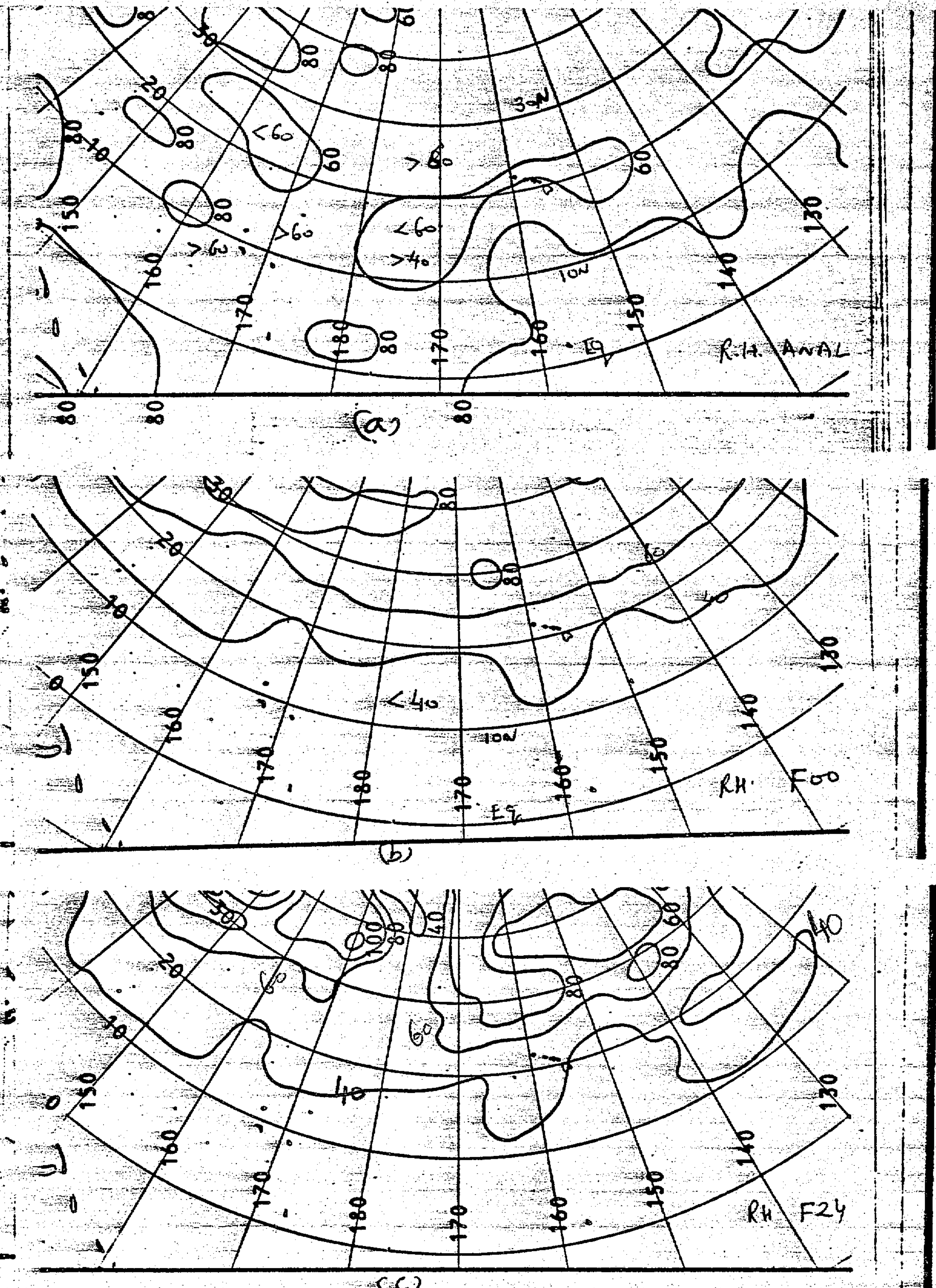


Fig. 14. Relative humidity in the first tropospheric layer: (a) ANL, (b) F00, (c) t=24 hr.

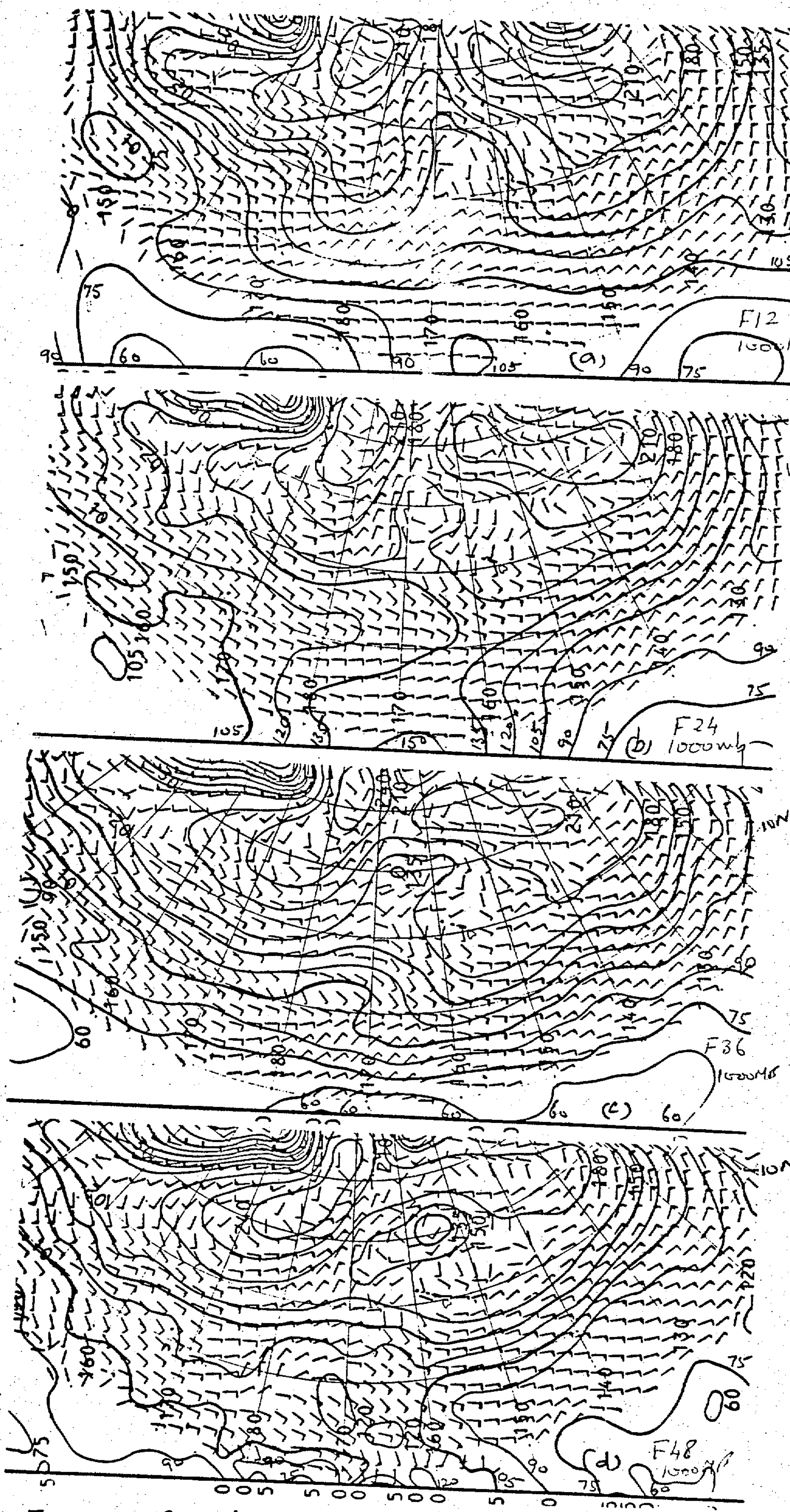
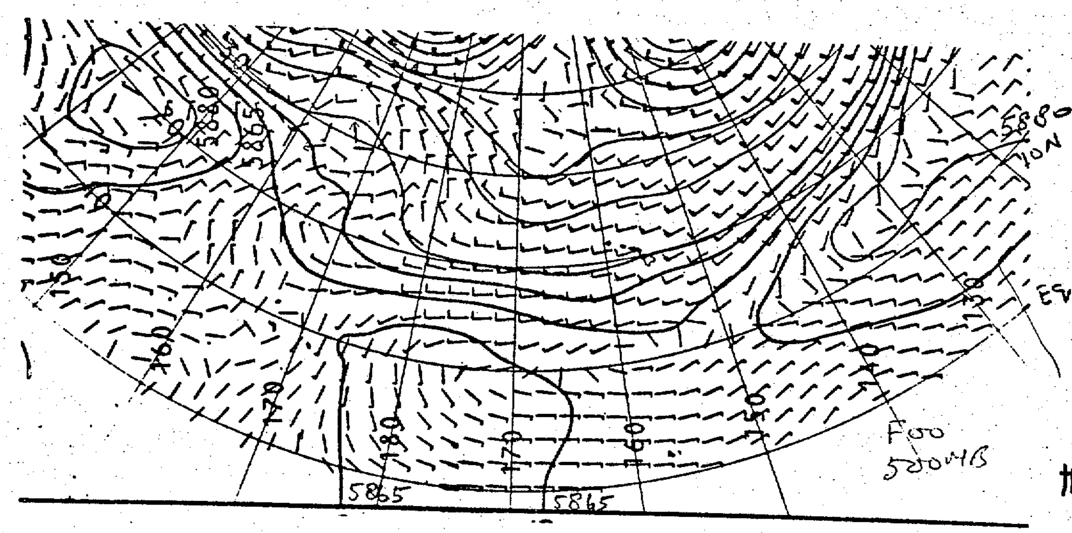


Fig. 15. Predicted winds and height analysis at 1000MB.
No surface Friction case: (a) t=12, (b) t=24, (c) t=36, (d) t=48 hr.



solution is better than in (4b)

Fig. 16. Winds and height at 500 mb. F00 field. $\nabla^2\phi = fJ$ is solved to the accuracy of 0.1 m, while in Fig. 4b, the accuracy is 10m (see Text).